THREE-DIMENSIONAL PLANT MODELING AND SIMULATION: HOW FAR DOES RECENT COMPUTER TECHNOLOGY EXPAND TO ASSIST THE LANDSCAPE ARCHITECTURE PRACTICE

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GRADUATE RESEARCH PROJECT

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DECLARATION

"I hereby declare that this thesis entitled **Three-Dimensional Plant Modeling and Simulation: How Far Does Recent Computer Technology Expand to Assist the Landscape Architecture Practice** is the result of my own research except as cited in the references."

Signature : ....

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بسم الله الرحمن الرحيم

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CONTENTS

FIGURES

1.0 INTRODUCTION

There are some contradict perceptions on the issue of advance digital application related to landscape architecture field. Either there is no advance digital application being invented for landscape architectural design purposes or another perception that there are probably few applications related to landscape architecture field but not being utilized by landscape practitioners in landscape design practice. This particular research topic on 'three-dimensional plant modeling and simulation: how far does recent computer technology expand to assist the landscape architecture practice' will answer the perceptions based on literature studies done by researchers all over the world as well as the recent information by the vendors which both related to this research topic will finally reveal the actual situation.

1.1 Landscape Architecture and Role of Landscape Architect and Designer

Landscape architecture is a field that involve with nature such as flora and fauna, landform and ecology and it has very close connection to architecture field where a building project might have landscaping work within the same project. Landscape design includes both softscapes such as plants and water bodies and also hardscapes such as pavement and pergolas. Landscape studies basically involves planting design, spatial arrangement, ecology, ecosystem, construction as well as master planning involving location, sizing, topography that can be an advantage in designing and planning a site for a stormwater management. It's also important to consider on landuse, zoning, circulation, utility and community of the surrounding. Site should be analyzed through site inventory and mapped with a different suitability assessment layer for each relevant factor. It has the quite similar work process with architect basically from site inventory, analysis and design process up till the outcome of few design alternatives through several presentations before final proposal. Thus, the role and task of landscape architect or designer is more or less equivalent to architect especially on its sequence of design process where it involves design, crit, presentation, amendments, documentations and in that case it need to be at par with the architects when it comes to computer application. Obviously, all these process will be much more faster, easier and accurate if it can be done with the help of computer technology.

1.2 Significance of Computer Based Technology in Landscape Architecture

Landscape architecture often involves with large scale of projects having huge site like parks whether it is open public park or even theme park, urban greenbelt or green corridors, campus and site design for institutions or housing areas, waterfornt or promenade, botanical gardens, arboretums, and nature preserves, recreation facilities like golf courses, amusement parks and even sports facilities. This is another good reason why it really needs a good computer application to assist the design process. Landscape design have so many element such as landform, plant materials, buildings, hardscape structure, pavement to be utilized in the landscape design that will be much more inspired with the help of the advance computer application such as the object information modeling from conceptualizing stage and the making and analyzing their design.

1.3 Integration of Conventional and Advance Computing in Current Landscape Architecture Work Process

Currently, the most popular way of doing the landscape design is the combination of both manual and computing. Some of the landscape architects have played a major part in the development of GIS and, with a CAD built-on, it is likely to become the most widely used landscape graphic software. McHarg's use of overlays in Design with Nature is accorded an important place in histories of GIS. When it comes to design process, most landscape architects still prefer to manually hand sketch his idea in a peace of paper and transfer it to CAD software for two-dimensional plan, elevations and sections. Most of them still draw the three-dimensional drawings manually saying that the plants will look more natural in freehand unlike building. Probably the lack of knowledge on the recent advances software provided that has a lot of two and even three dimensional plant software available in the market.

Nevertheless, no doubt that many landscape architects now have used digital plant library in computer database to do plant selections but it only limited to still images not object modeling that can work for simulation and animation. As for presentation, the still drawings done in two-dimensional CAD will then be rendered and coloured either manually or using computer. For photo-editing work landscape architects will make use of image-editing software (eg Photoshop and Photopaint). These programs encourage exploration of photomontage as a conceptual and graphic tool. Having said that, there are a lot more opportunities to integrate even more computer technology available for landscape architecture field created in the market. However, there is no effort of taking the advantage of manipulating every advance computer application emerge recently and make full use of it in design process as early as possible. Danahy (2001) believed that the role of a computer-aided-design system should be to assist the designer in developing and managing the information used in a complex environment design problem and to allow for accurate rendering of all design alternatives considered. Visual information generated by the computer will definitely influence on decision-making when being used as early as possible in the design process. Sad but true, most of these advanced visualizations are developed only after the real work is completed, and often only to 'sell' the resulting proposals for marketing purposes.

1.4 Issues and Problem Statement

Unfortunately, unlike the architects, those landscape architects are still few steps behind when it comes to computer technology application and utilization within their design process. Almost all landscape design practitioners are still comfortable and satisfy using the manual approach in handling the design exploration and presentation techniques. These won't allow the landscape design professions to be able to expand to a collaborative design strategy. Within contemporary digital environments, there are increasing opportunities to explore, analyze and evaluate design proposals which integrate both architectural and landscape aspects. The innovation of integrated design solutions exploring buildings and their surrounding context is now possible through the design development of shared three dimensional and even four dimensional virtual environments, in which buildings no longer float in space.

There are presently still too many landscape architecture practitioners as well as in academic departments where computer based design activity is seen as an isolated from the whole design process where it is only be used more for two dimensional instead of three dimensional tasks. With recent technological developments in computing, there is a huge opportunity for a range of landscape element and component template and rich information modeling to be explored. An increasing amount of online data is large and available compared to years before. A rapidly expanding area related to landscape architecture is Geographic Information Systems (GIS). Another expanding area is the use of object-oriented technology in CAD.

Nevertheless, for this particular research paper, I will explore on plant as the main object for the information modeling and the possibilities to be applied in landscape architecture design practice towards better possibilities of having an effective design and time consuming results. Eventhough plant is obviously one of the main elements in landscape design, there is still conventional method in addressing the plant in the design process.

The main and leading character of visual landscape simulation are plants, the aspect that has traditionally proved to be one of the greatest challenges for landscape representations. Paar (2006) also believed that as most landscapes are covered with vegetation, the representation of plants and vegetation is a prerequisite for realistic visual simulations of landscape sceneries. Furthermore, plant itself is the primary character in visual landscape simulation. This clearly stated that a digital application related to plant is vital.

The absence of plant information modeling software is a huge disappointment since choosing and analyzing plant is important. Without using the correct plant selection in addition of having a good landscape design and planning, the level of success would not be so great. As Preece (1991, p.256) says that trees are joy, but the wrong tree in the wrong place is nuisance. Due to that reason, this research will mainly be focusing on the plant material particularly in three dimensional plant modeling and simulation where this is main issue lacking in the landscape design application.

1.5 The Capability of the Latest Advance Computer Application Related to Landscape Architecture Field

Significant increases in the performance of computers are now making it possible to move on from symbolic representations towards more contextual and meaningful representations. For example, the application of realistic materials textures to CAD-generated building models can then be linked to energy calculations using the chosen materials. It is now possible for a tree to look like a tree, to have leaves and even to be botanically identifiable. It will be good to have more realistic effect like having parametric value for instance the density of leaves or length of branches and are capable of surprisingly informative and realistic simulation of each landscape elements. In other words it should be information rich modeling approach. In the effort to model and visualize landscapes, we need to seek a balance between ‘look like’ and ‘acts like’. It is easy to have the plant that ‘look like’ plant but it is difficult to achieve plant that ‘act like’ or ‘behave like’ plant. The building and landscape can be rendered from a common database of digital samples taken from the real world. The complete model may be viewed in a more meaningful way either through still images or animation, or better still, through a total simulation of the lifecycle of the design proposal. The model may also be used to explore environmental/energy considerations and changes in the balance between the building and its context most immediately through the growth simulation of vegetation but also as part of a larger planning model. The latest one can predict what it may look like in future time for example the effect of the plant growth after five or ten years ahead. These will help to predict how the shading or visual created by plants will affect the building or even the landscape sceneries after few years.

Surprisingly, there are ample of interactive modeling of plant application nowadays. Observing the current landscape practice and educational exposures in academic level, one would think that there is no advance plant modeling software at all available but amazingly it does. In this digital modeling field a lot of method and system created to model a plant such as Texture Mapping, Fractal and Lindenmayer system or known as L-system used in the earlier stage up till recent ones such as LIGNUM, Canonical GUI system and Lenne´3D system where these latest systems are an improvised version targeted at previous limitation and weakness of earlier invention. Integration of more than one approach will give much better result. For instance the combination of L-system with LIGNUM or canonical modeling with L-system. More software applications which offer plant modeler application emerged based on some of this system such as TREESTORM by Onyx TreeMaker, EASYnat by Bionatics, Lenné3D, SpeedTree, TreeMagik, PlantStudio, Plant-Life and XFrog. All these would be explained further in the following topics.

Plants not only complex in their basic structure, they also represent another dimension altogether in the landscape which is dynamics and change over time. Plants grow on an annual cycle, sometimes changing their form dramatically, and not just by simple scaling; many change character on a seasonal cycle, shedding, re-growing and re-colouring their foliage; and often plants move and change with daily solar cycle as well as shake and sway with the wind. Ervin (2001) also believed that modeling a tree's basic geometry is a daunting challenge; making it grow and change overtime or blow in the wind (digitally) is even more so. Some software has begun to approach these challenge, adding to fractal plant-form generation, plant growth or wind motion, and these are already essential utilities for digital landscape modelers such as those mentioned before.

2.0 PLANT DATABASE

2.1 Intelligent Sources of Digital Plant Database

Plant or may also be termed as vegetation is consists in various categories. In landscape architecture field plants are categorized into trees, shrubs, palms, bamboos, vines (climbers and creepers), groundcovers and also aquatic plant. Those categorization are sort based on their physical characteristic. In landscape practice, landscape architect or designer will need to choose an appropriate plant based on the design concept and theme, design principles and most importantly objectives because different plant serves different landscape function. Plants are selected based on its characteristic and landscape function, suitability as well as aesthetic. Traditionally, all these information are gathered in books with all the images. Then there is electronic library or e-library where it is a digital library consists of plants species with every botanical information including still images.

Information of plants characteristics such as shape and profile, size of maturity, nature of foliage, special features of value, rate and pattern of growth, strength of wood, flowering habit (can see what it looks like in summer, autumn, winter and spring effect whether its evergreen or deciduous) are included in the database.

Recently, some of these plant databases have been equipped with three-dimensional images instead of two-dimensional images of plant. AMAP stands for Atelier de Modelisation de Architecture de Plants is a commercial library of plants is one of the pioneer in virtual nursery field. Many researches have been using AMAP plant database where they used plant images generated by AMAP and simulated various landscapes using the AMAP system.

Honjo and Lim (2003) experimented a research digital plant modeling to express plant by texture mapping also using computer graphics images of plants made by AMAP where he claimed that AMAP is a high-performance visualization system for landscape planning developed by Center Internationale Recherche Agricultural Development (CIRAD) that produces high precision three-dimensional plant shapes. AMAP is one of the outputs of the study of plants. AMAP generates very botanically realistic three-dimensional computer graphics where images of several growth stages can be easily made and are used as a texture. This three-dimensional plants made by computer graphics by AMAP or other similar techniques consist of polygons. Branches, twigs, flowers and leaves are all described by sets of polygons. The number of the polygons varies between thousands to millions. Such a polygon model is suitable for photo realistic expression of the plants but needs large amount of time for the rendering and additionally, walk-through simulation is difficult in VRML. Therefore, this method used only 2D textures and a 2D plant image database was developed. Examples of plant images in the database are shown in Figure 1.

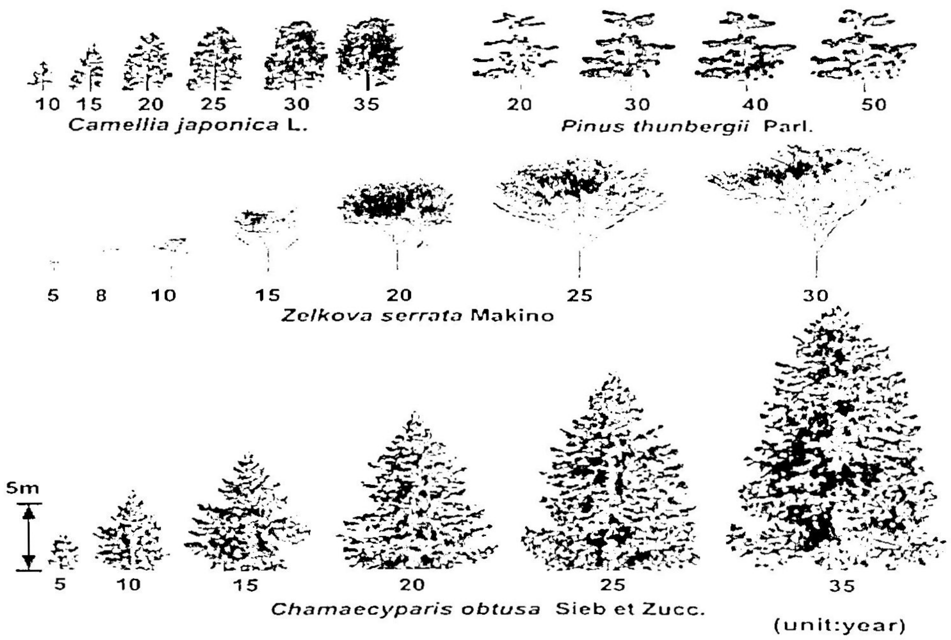


Figure 1: Examples of plant images in the database. *(source: Honjo and Lim, 2001)*

This texture mapping method using the 2D image from AMAP database is one of the earliest method used. To make a fast rendering of plants, the texture of plants which are in a transparent GIF format are mapped on a plane and two planes are crossed to show the plants as shown in Figure 2. This method is very effective for the fast rendering of plants thus make it very popular. There are many methods to model plants. Muhar (2001) claimed that the use of texture mapping in connection with simple 3D-faces is a very popular method of plant visualisation in landscape architecture. Texture mapping implies the projection of raster graphics onto a modelled surface in order to alter the surface characteristics, such as the colour or the transparency. In the case of plant visualisation a photograph of a real tree can be mapped onto a rectangular vertical face (billboard); in the rendering process the areas of the image background are treated as transparent shown in Figure 2 and 3.

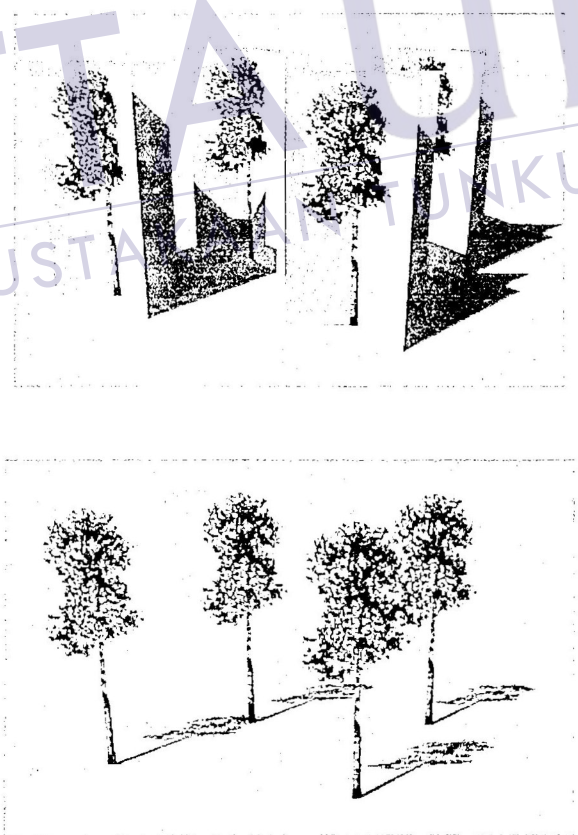


Figure 2: Plant simulation via texture mapping: a tree image is mapped onto a simple rectangle. The background colour of the image is rendered as transparent. One such "billboard" faces the viewer, a second one faces the sun and is only used to cast a correct shadow. *(source: Muhar, 2001)*

Plants consist of a large number of individual elements, however, the configuration of these elements follows relatively simple rules (e.g. the branching pattern within a genus is usually constant). Therefore, plant modeling algorithms have to find ways for a formal mathematical description of the 'genetic construction plan' of a plant.

Figure 3: Example of trees images made by two textured planes with transparent GIF and non-transparent GIF. *(source: Honjo and Lim, 2001)*

This texture mapping is a starting point of more inventions of plant modeling and rendering application. Danahy (2001) strongly believed that the breakthrough for three-dimensional landscape simulations came when image-processing techniques were merged with geometric modeling. These techniques, referred to as texture mapping, have constituted a "profound improvement", as they have enhanced image quality and opened the door for real-time rendering of virtual models. In this hybrid approach, much of the explicit, realistic information is sampled from the real world and is not computed (e.g. leaf texture in 3D plant models). Using an expression of a plant's genetic code, AMAP technology constructs virtual models of plants and trees that are botanically coherent. It reproduces an infinite number plant, each unique, true-to-life and simple to generate and animate. For the first time ever, virtual "living" models can simulate with realism the evolution of a project within its space and time.

Another popular method for modeling a plant is L-system. Renton et al. (2005) explained that these L-system models can give a topological, geometrical and graphical representation of the plant. In L-system models the development of a plant's structure is expressed as a changing string of symbols where each symbol represents a plant component such as a leaf, internode or apical bud, with square brackets enclosing lateral structures in Figure 4.

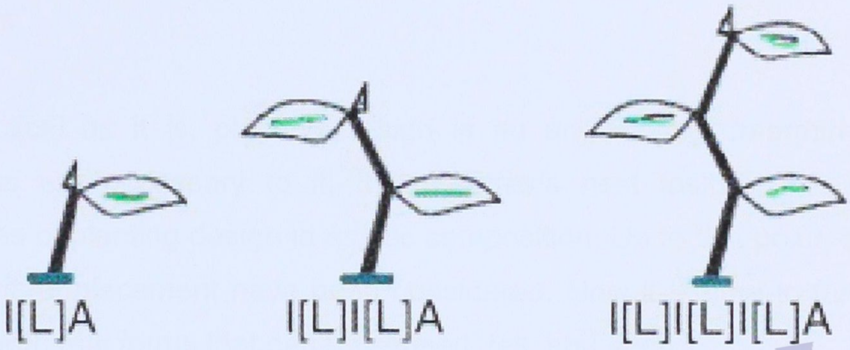


Figure 4: Consecutive stages of development of a plant modeled by a simple L-system with production rule A → I[L]A. The structure is represented by a string of characters that changes over time. I stands for an internode, L represents a leaf and the apical meristem is symbolized by A. *(source: Renton et al., 2005)*

The dynamics of how the string symbols change is controlled by a set of growth or production rules. This resulting dynamic plant structure can then be visualized in realistic or schematic ways, easily related to the appearance and architecture of real plants.

3.0 PLANT MODELING

Vegetation can be modeled either at the level of individual plants or as a terrain texture. The plant modeling method is determined by the objective whether to perceive the plant as in individual or in a whole bunch as in a forest. It is important to determine the scale in order to achieve good level of detail. Muhar (2001) clearly described the difference in scale-dependant visual perception of vegetation where at object scale, a plant is perceived as a complex structure, consisting of a large number of individual objects like leafs, flowers, twigs, trunks, etc. whereas at landscape scale, vegetation is usually perceived as a texture of the terrain; individual plants cannot be distinguished. In other words saying that plants in the foreground of a scene have to be modeled as three-dimensional objects, while for the background other approaches can be applied, such as texture mapping. However, for landscape architectural design purposes, most plant would be modeled as single / individual instead of forest strand.

3.1 Significance of Plant Modeling Application in Planting Design Process

As practical as it is, planting design is an art. Having determined what functions are necessary to it, the designer's next task is to apply the principles of planting design in artistic composition. Up to this point, only size and general placement have been considered. Now it is time to furnish the design with real forms that can be sensed, felt, and seen.

Planting design process which includes planting design principle, planting design purpose, planting design arrangement and spacing (mass/group) really need such advance application. Planting design purpose would considered on aesthetic value such as flowers and foliage, an abstract value such as lines, shapes, forms, textures, colours and visuals, a functional value such as shade, barrier, hedges and screen. To choose and analyze the impact on this can be assist by advance application.

Plant materials have many sensory qualities. We can see their characteristic in various forms, textures, and colors. We can feel their textures. We can smell their fragrances. We can even taste their foliage, blooms, and fruit. But in order to create a pleasing landscape design, we must coordinate the functional uses of plants with our sensory perceptions. We can see plants in various forms or shapes, colours and textures. Although the form of each plant is unique, there are general classifications of forms. Trees can be round, columnar, conical, oval, spreading, weeping/willowing, vase-shaped or pyramidal which can be seen in Figure 5. The outline of a tree depends on its branching pattern. Narrow and crotch angles at the point where lateral branches separate from the trunk cause upright forms; the more rounded forms are caused by wider angles.

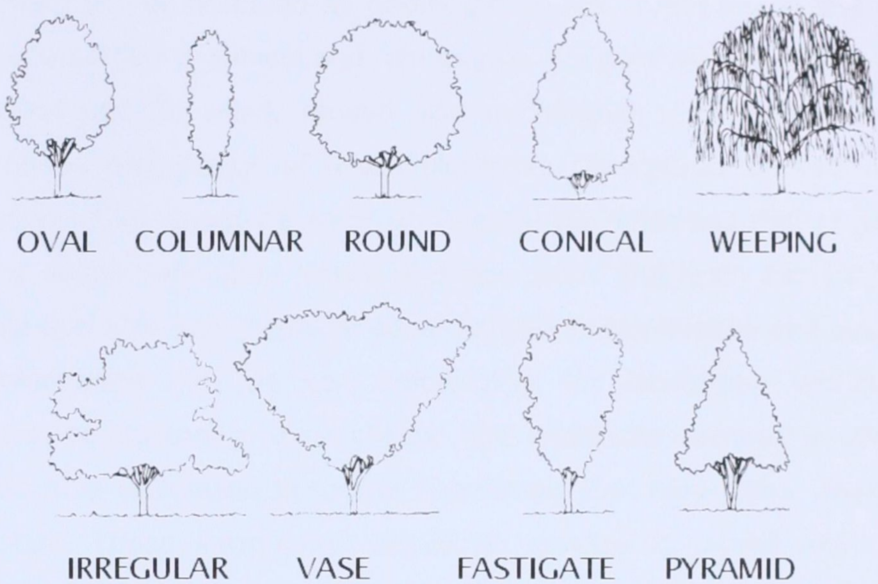


Figure 5: Plant form and shape. *(source: Renton et al., 2005)*

Growth pattern and habit should always be considered to be an element of form. Colours of plants also important to be well visualize in computer modeling to achieve better impact whether to get warm or cool or striking effect as can see in figure 6. All these would make the plant modeling application can become significant to assist landscape architect in planting design process work flow. Due to that reason, such application which offers a rich information modeling of plants would be so much needed to assist the work flow of planting design process in order to achieve effective results.

Figure 6: The impact on colours in visualization *(source: author 2007)*

3.2 Rich Information Modeling

Since plant can be modeled as geometric objects it can have plant data or information of both graphical and non graphical aspect related to it where this information can be used, reused and exchanged with integrated 3D-2D model-based technology, of which electronic documents are just a single component. This would be such an informative database that is gathered within a single repository which includes both graphical documents like drawings and also non-graphical documents like specification and schedules. This information can be very informative for landscape architects or designers, contractors or even clients. The information related to plant may be taken from authorized botanical department that have done research on each plant. These information would be needed to model and run the simulation analysis of the plant targeting on desired design factors for instance shade effect by plant canopy or some more factors that would be discussed on further topics. This innovative method of the latest digital technology enable to efficiently generate and exchange information, create digital representations of all stages in design process and also simulate real-world performances.

3.3 Plant as an Object-Based Modeling

Plant can be considered as an object just like building where building has various sizes and amount of walls, doors or windows, plants also have various sizes and amount of leaves, branches or flowers. As been mentioned earlier where at object scale, a plant is perceived as a complex structure, consisting of a large number of individual objects like leaves/foliage, flowers, twigs/branches, trunks and more. Objects are parametric. This means that any object's basic parameters given in parameter list is editable. Taking an Archicad as an example where the basic parameter are its length and width dimensions, users can freely change the parameter of the object using the Object Settings dialog box. Archicad also allows its user to customize other dimension parameters.

3.4 Parametric Modeling Technology

Parametric Modeling technology is one of the advance mechanisms in rich information modeling. This parametric modeling engines that normally used parameters consists of numbers or characteristics is to determine the behavior of a graphical entity and define relationships between model components. This advance parametric option should also be introduced in any plant information modeling software. The shape and configuration of which is characteristic for the visual impression of each species. Parametric value of plants components and characteristic should be able to allow landscape architect and designer to see the desired plant object to achieve certain design objective or clients criteria and also to foresee the impact in real-time.

Information on plants modeling should include characteristics such as shape and profile, level of maturity/size, nature of foliage, special features of value, rate and pattern of growth, strength of wood, flowering habit (can see what it looks like in summer, autumn, winter and spring effect whether its evergreen or deciduous). Some might be fixed or automated and some parameters should be adjustable as in parametric value such as overall height and trunk height, branches pattern and spreading width, canopy diameters, density of foliage and certain flower colour option referring to available species with more than one colour.

Nevertheless, there should be certain scripting for certain rule set in order to limit the parametric value input such as the maximum and minimum range or value of each points for instance the height value of the trunk should be between a minimum and maximum value as referred to the actual height for each species received from a certified botanical research department. By having this constraint, it would make sure that the input value will be in logic with the actual plant. Most importantly, whenever certain parameters are change, the plant can be previewed instantly in three-dimensional mode to see the effect for instance to see the shadow effect.

Landscape architects or designer are involved in many decision-making processes in their daily practice which normally consist of design, predict and critique through a series of assessment. They would generally approach the problems by processing the available information of the site which is the real world, considering the interrelationships of site entities, developing a mental model with criteria, opportunities, and constraints. At the same time, designers start to develop different concepts and ideas for the design solution though these concepts may not be mature until later on stage. Evaluation of alternatives and simulation of impacts would more effective if it's being done in an advance way as early as possible to avoid hassle towards the end.

4.0 ANALYSIS AND SIMULATION

Analysis should be done through three-dimensional simulation in order to see and foresee clearly the effect on the planting design proposal that cannot be seen on two-dimensional drawing papers such as shadow casting, plant growth, function, bending and swaying as well as seasonal effect.

4.1 Plant Shadow Casting/Underneath Shade

A landscape architect or designer should now be able to simulate the effect of shadow created by the plant at various angles of view and duration of time and perform few alternatives for comparison analysis through this advance digital technology. This simulation model will help the landscape architect or designer to 'postdict' the result of a site design as well as 'predict' the outcome of future observations. Different species of plants have different characteristic for their canopy shape such as round, columnar, conical, oval, spreading, weeping/willowing, vase-shaped, pyramidal, and lots more. By having this rich information modeling on plant characteristic and components, simulation analysis can be performed to foresee the shadow effect received for different species so that landscape architect or designer can get clearer idea in doing the right plant selection to suit the design objectives. Some plants do have good canopy shape to provide better shade underneath its canopy that will suit the design for seating beneath a tree in a park. Patterns of light and shadow depend more upon individual leaf surfaces in a tight, dense shape; in a loose structure, the masses of leaves and corresponding voids dictate light and shadow

4.2 Plant as Landscape Function

Besides performing analysis on shadow, this simulation model will also be able to simulate the effect on landscape function of the plant. Each plants are selected and arranged in a certain design objectives or criteria either for its functionality or aesthetic purposes. Both can be analyze through this plant simulation model in order to foresee the effects for instance the objective for a plant is for barrier or hedges purposes, in this case through rich information modeling of parametric options on each plant's component will let the landscape architect or designer run the analysis through simulation of plant's foliage/leaves density or planting arrangement density in order to receive maximum target of barrier or hedges effect.

4.3 Plant Bending and Swaying Simulation

Finally, through many experiments were carried by some researchers, now the real-time animations of swaying trees in the wind can be realized. Viewing would be much more fun and easier and evaluating would be more helpful through shadow casting effect and wind-blowing effect will be seen in any angles that can also be controlled by user through 360° Billboards effect. Plants may now not only 'look like' but also 'act like' or 'behave like' plant with swaying through wind force from various angles and various velocity as well as growing and changing colours through times. Akagi and Kitajima (2006) proved in his research that real-time animation of trees swaying in the wind based on physical simulation can be achieved through his series of experiments.

The tree shape models generated by this technique also have parent/child relationships and various parameters with regard to shapes of branches and leaves such as the length and radius, the number of child branches/leaves, branching angles and branching positions. With this model, the deformation of branches caused by wind is relatively easy to deal with by defining the relationship between wind forces and branch bending and the transmission of force between tree parts. In the tree model of our study, the section connecting a certain branch with a child branch or leaf is called a "contact point" (a fixed section). A single branch, moreover, is divided into the seven parts of cone-shaped "links" that are interconnected by six "joints." Each link here is considered to be rigid and only joints have the freedom to rotate.

The bending of a branch can therefore be expressed by the rotation of each of its joints as shown in Figure 7. Figure 7 and 8 shows the bending simulation while figure 9 and 10 shows the tree swaying simulation by wind.

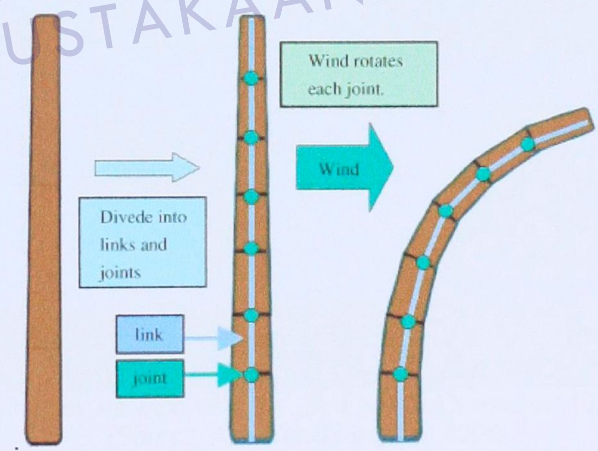


Figure 7: Bend of branch. *(Source: Akagi and Kitajima, 2006)*

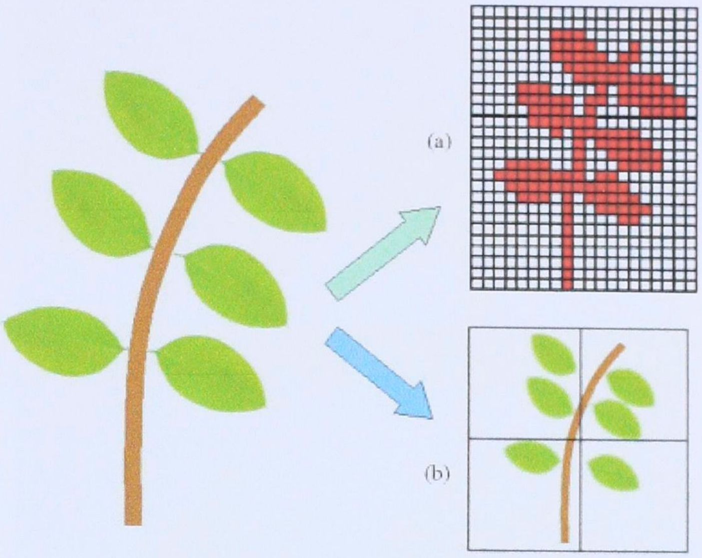


Figure 8: Virtual resistance: (a) ordinary grids and boundary conditions to compute the wind; and (b) using virtual resistance to reduce the amount of grids. *(Source: Akagi and Kitajima, 2006)*

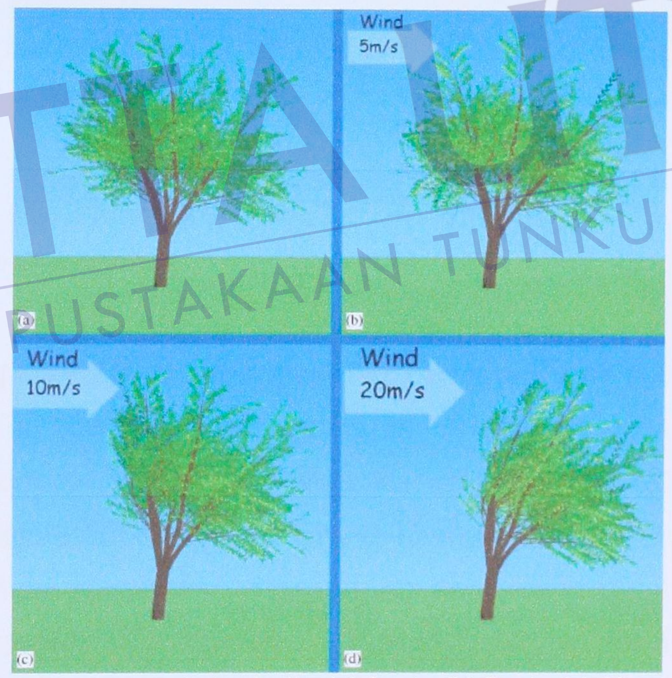


Figure 9: Tree swaying versus wind velocity: (a) 0 m/s; (b) 5 m/s; (c) 10 m/s; and (d) 20 m/s. *(Source: Akagi and Kitajima, 2006)*

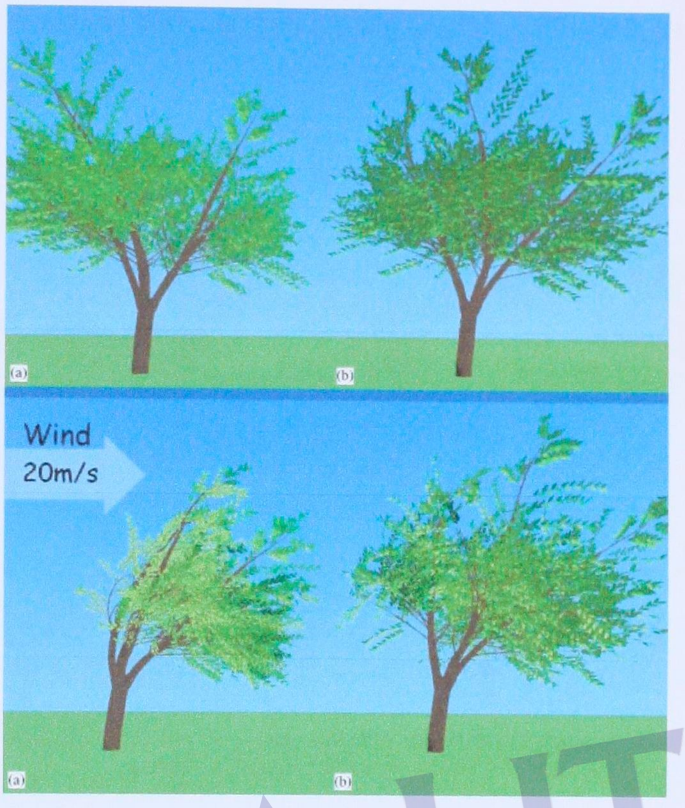
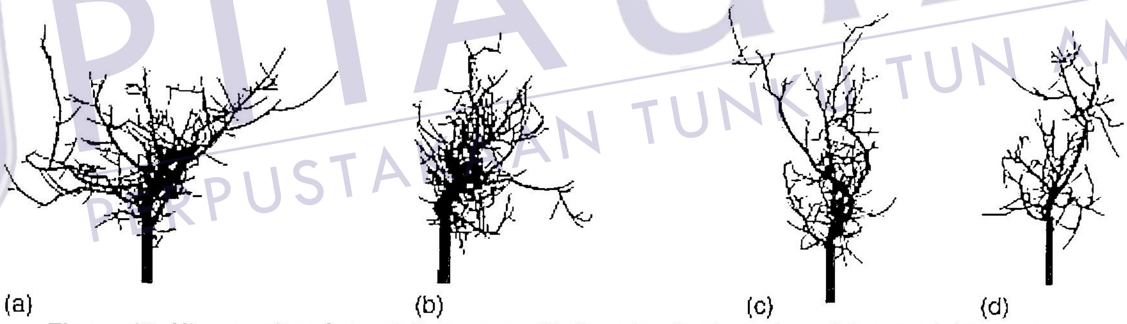


Figure 10: Effect of tree on the upwind side on the sway of branches: (a) upper wind and (b) lower wind. *(Source: Akagi and Kitajima, 2006)*

4.4 Growth Simulation

It is rather important to foresee what the plants will look like in the future. Besides knowing how the plants is going to look like when they are growing taller, the simulation can also shows the growth result affected through shading and defoliation and also seasonal change. Some of the recent digital technologies have succeeded in performing this growth simulation. Renton et al. (2005) revealed the simulation of plant growth where he successfully integrates an L-system-based representation of structural development, a canonical model of plant function, and stochastic allocation rules based on empirical architectural data analysis to produce an integrated structural–functional model that simulates the development of the structure of the birch tree over time. This can be seen in Figure 11, which show the model output from two different model runs after 2, 6, 10, 18 and 50 years. The complex final structure emerges through the simple process of adding long shoots at each time step.

Figure 11: The results can also be differ affected by different impact on shade and light pattern. *(Source: Renton et al., 2005)*



(a) (b) (c) (d)

Figure 12: The results of simulations run with the standard version of the model to test adaptability to variable growth patterns adapting different shading conditions. Simulated of 20 years old trees growing (a) in isolation of full light, (b) left side shaded (c) in a forest and (d) in isolation with 75% annual defoliation simulated in the canonical model. *(Source: Renton et al., 2005)*

However, the allocation routines are sensitive to light, with a bud that receives more light more likely to produce a new long shoot. Figure 12b shows the results of assuming that buds on the left side of the central axis of the canopy are shaded and receive 65% of full light, while Figure 12a results from assuming that all buds are in full light. The altered allocation pattern is obvious.

Besides L-system (Lindenmayer systems), LIGNUM also is also focusing on growth simulation. LIGNUM system try to depict the dynamics and growth of woody perennial plants by assessing the physiological processes in their three-dimensional arborescent form. LIGNUM model for structural dynamics of trees. LIGNUM is a functional-structural tree model that represents coniferous and broad-leaved trees with modelling units corresponding to the real structure of trees. The units are tree segments, axes, branching points and buds. Metabolic processes are explicitly related to the structural units in which they take place. The tree in LIGNUM consists of components that are similar to real tree parts. Both metabolism (i.e., photosynthesis, respiration etc.) and crown architecture are accounted for. Perttunen and Sievanen (2005) described LIGNUM is intended as a generic model for both coniferous and broad-leaved trees where different tree species can be simulated by implementing models of metabolism, structural dynamics of birth, growth and senescence, and by realizing branching rules for distinct tree architectures. He also briefly present the main features of the model in order to understand how LIGNUM is adapted to use L systems where LIGNUM represents the three-dimensional aboveground part of the tree with four structural units called tree segment (TS), bud (B), branching point (BP) and axis (A). A branching point is a set of axes. An axis is a sequence of tree segments, branching points and terminating bud. This captures the recursive structure of the tree crown.

The most important functioning unit is the tree segment, i.e. the section of woody material between two branching points. For conifers the needles are currently modeled as a cylindrical layer of foliage surrounding a tree segment as shown in Figure 13 left. For broad-leaved trees leaves are attached to recently formed tree segments and are modeled explicitly using a simple geometric form such as an ellipse to represent the leaf shape as shown in Figure 13 middle.

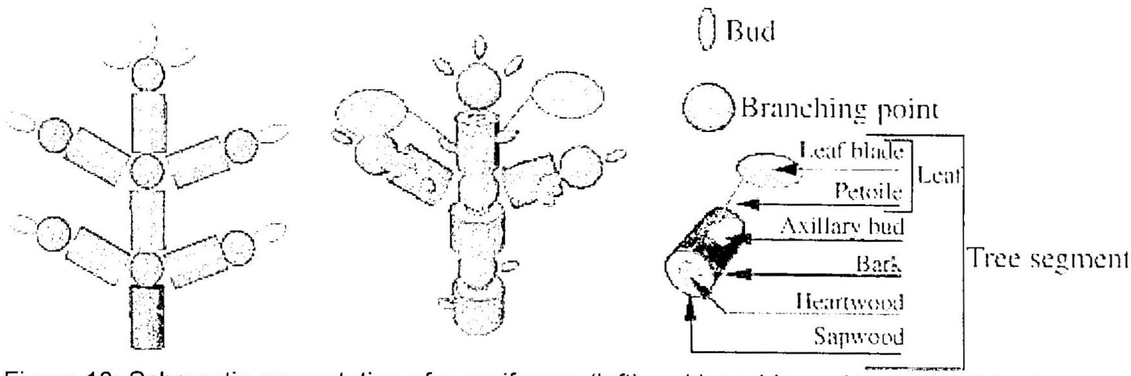


Figure 13: Schematic presentation of a coniferous (left) and broad-leaved tree (middle) using structural units of LIGNUM. Also shown is the structure of a segment (right) for broad-leaved trees. *(source: Perttunen and Sievanen 2005)*

LIGNUM model has been interfaced with L systems for specifying formally the architectural development of trees, thereby improving the applicability and ease of use of this functional-structural tree models. LIGNUM represents the three-dimensional aboveground part of the tree with four structural units called tree segment, bud, branching point and axis. LIGNUM also allows user to study various effects of light. On the left the parameter values have been adjusted so that the tree can be said to have adapted to grow in a shade; each tree segment can utilize even a small amount of light. The form of the tree follows its function. In the middle the parameter values are adjusted so that the tree segments are sensitive to shade. Notice how the lower branches are dying due to the shading of the crown as a result of this property. The result is a tree that mimics a sapling in a Scots pine stand. Again, the form follows function. The rightmost tree simulates a tree growing beside an obstacle. The effect of the obstacle can be achieved by blocking the solar radiation from one side of the hemisphere.

Unfortunately LIGNUM only has few species which is under coniferous and broad-leaved trees. Nevertheless, since it has succeeded in modeled and simulate tree growth, this approach can be improved and expanded for the future development of LIGNUM in modeling trees and forest stands.

4.5 Seasonal Simulation

Plants grow on an annual cycle, sometimes changing their form dramatically, and not just by simple scaling; many change character on a seasonal cycle, shedding, re-growing and re-colouring their foliage. Like to other simulation such as plant growing, swaying and bending and movement, seasonal simulation would is not impossible to achieve in this current application where some software are already simulate the changing of plant looks and behavior in four different season from autumn, winter, spring and summer with the natural effect of seasonal cycle. A deciduous tree shed their leaves, with the leaves changing to a reddish or brownish hue before falling. Such coloured leaves have come to be colloquially called *"fall foliage"*. This application might not be so useful to landscape architecture and designer compared to plant growth simulation though it will give some visual impact on how a certain landscaping project will look like when every plant chosen is deciduous instead of tropical plants which is mostly evergreen.

Figure 14: The different effects on same plant model resulted by seasonal simulation.
(source: Bionatics application, 2007)

5.0 APPLICATION

Recently, a vast growing number of commercial plant modeling and visualization application which enable to perform advanced animation and simulation has emerge in the market such as TREESTORM by Onyx TreeMaker, EASYnat by Bionatics, Lenné3D, SpeedTree, TreeMagik, PlantStudio, Plant-Life and XFrog. However, some plant modeling software like Treemagik, Speedtree, Plant-Life and XFrog are meant for the use in